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two almost imperceptible markings appeared adjacent to its eastern side, and on the 7th commenced to develop, forming large penumbral tracts with several small nuclei. The nearest spread into connection with the large spot, and the group then extended over an area 140,000 miles long when on the center of the disc. Having observed the Sun for the past eight years, and preserved drawings of the principal spots, comparison shows that during that period it has been equaled only by those of February, 1892, and August, 1893, in compactness and extent. Though it seemed lower on the disc, owing to the position of the plane of the solar equator on those days, measurement placed it between south heliographic latitude 8° and 15°.

SUN-SPOT,
SEPTEMBER 3D,
2:30 P. M.

It may have been the development of a very small spot that commenced its existence towards the center of the disc on August 11th within the same latitude; otherwise, it cannot be traced as the continuance of any previous disturbance, and must have formed on the unseen surface in the latter half of August.

The final chapter in the career of this unseasonable solar storm is its return in due time on September 28th in the form of two small spots with dark nuclei. On the 30th one of much larger size followed them, but it could not be classed as a remnant of the giant storm, though its position was suggestive of a common origin.

SAN FRANCISCO, October 13, 1898.

THE TEMPERATURE OF THE SUN. II.

By PROF. DR. J. SCHEINER.

[Translated from the German in *Himmel und Erde*, by FREDERICK H. SEARES.]

It is a fundamental law of all exact investigation that the investigator should not be satisfied with the derivation of an important result in the most direct way alone, but that he should strive by other means, or by indirect methods, which, under certain circumstances may be very complicated, to arrive at the same result. Only when this has been done, where the same end has been reached by following different lines of thought, can the result be said to have been established. Frequently it happens that, in consequence of the nature of the problem, the methods which can be applied do not lead to definite numerical values; in these cases the investigator must be satisfied with a result which sets only an upper or a lower limit, or perhaps places the desired result within two limiting values. Such is the case in the problem we are considering; we can by the use of indirect methods obtain only an approximate confirmation of the value of the solar temperature given by the direct method.

We shall now examine these so-called indirect methods, and discuss those possessing the greatest similarity with the direct method, inasmuch as with them the solar radiation is directly involved.

It is a fact known to every one that the small image of the Sun formed by a burning-glass or burning-mirror possesses a very high temperature. With even a small lens one can almost instantly ignite bits of wood and paper. A number of years ago CERASKI, in Moscow, with a very perfect burning-mirror of one meter diameter, carried out a most interesting series of experiments. He succeeded in melting, burning, and vaporizing in the focus of his mirror all of the substances accessible to him, and his estimate of 3,500° for the temperature in the focus appears not unreasonable. From this it follows directly that the solar temperature must be higher than 3,500°; for there exists a well-founded law of the mechanical theory of heat, to the effect that of two bodies the colder can never increase the temperature of the warmer; on the contrary, the opposite phenomenon always occurs. Consequently, no crowding together of the solar rays by a burning-glass can create a temperature greater than that of the Sun; otherwise, we should have the relatively cold Sun increasing the heat of the relatively hotter focus. In fact, heat is lost in the transfer through absorption and imperfections in the glass or mirror, so that the temperature of the focal point must always be lower than that of the solar surface. This conclusion, not so easily to be passed by, can be made more plausible by the following considerations: A condensation of the rays by a lens or mirror is equivalent to an increase in the apparent extent of the radiating body (the Sun), or, to a diminution in its distance. Under the most favorable circumstances, the equivalent distance of the real Sun corresponding to the focal temperature would be zero, which means that at most the focal temperature can only equal the solar temperature, never exceed it.

In order to obtain a comparison with other temperatures

CERASKI measured with the same mirror the temperature increase in the focus produced by the radiation of an electric arc of the same apparent diameter as the Sun. He found an amount varying from 100° to 105°. From the enormous difference, as compared with the action of the solar radiation, CERASKI concluded that the solar temperature must be far higher than 5,000°. This conclusion is correct. If we apply STEFAN'S law to CERASKI'S data we obtain a temperature of over 3,000,000°. This number so flatly contradicts the results of the previously discussed direct methods that we can at once declare that some factor has been overlooked in the investigation; apparently, it arises from the use of the electric arc as the radiation source, for considerable difficulties are met in the arrangements of the experiment.

The first to attempt to determine the solar temperature from a purely theoretical standpoint was ZÖLLNER. He assumed the protuberances to be streams of gas from the center of the Sun generated by great differences of pressure; then, assuming further the laws governing gases in their terrestrial relations to be valid for the solar conditions, he was able to derive a value for the temperature of the solar surface which he considered to be liquid. For this surface he found the temperature 13,230°, with a rapid increase for increasing depths below the surface. For a point whose depth is one fortieth the solar radius the corresponding temperature would be 1,112,000°.

Later ZÖLLNER used another method, somewhat more free from assumptions, which by ingenious considerations afforded for the uppermost limits of the photosphere the value 61,350°. At the present time ZÖLLNER'S investigations have only an historical interest.

Upon the assumption that the Sun glows as a ball of gas, that the photosphere therefore does not to any extent radiate heat and light arising from suspended glowing particles, EBERT has given a determination of the solar temperature. He considers the radiation to be electro-magnetic in its nature, and although it is not possible to give here the details of his discussion, the final value obtained is 40,000°; but it is to be remarked that this number corresponds not to the uppermost limit of the photosphere, but to a deeper layer, where the gases are under much greater pressure.

Free from all assumptions as to the constitution of the Sun, and depending only upon the validity of KIRCHHOFF'S law, is a determination of the solar temperature, and at the same time of that of the fixed stars, made by the writer several years ago. It rests upon a remarkable relation existing between two magnesium lines in the blue part of the spectrum. The first of these lines appears strong in all the spectra of the stars of Class I; in the spectra of Class II, to which our Sun belongs, it is weak; and in those of Class III it appears to be wanting. In the electric spark of magnesium the line is strong, but, on the other hand, it does not appear either in the electric arc or in burning magnesium. Remarkably enough, the second line presents the opposite phenomena, both in the stars and in the laboratory. The favorable circumstance that two lines belonging to the same substance should show an opposite behavior proves at once that the phenomena presented by these lines in the stars depend only upon the temperature, and not upon the pressure or density of the gases in the atmosphere. One thus arrives at the conclusion that the temperature of the photospheres of the stars of Class II (Sun) is somewhat higher than that of the electric arc, but considerably lower than that of the electric spark. As a lower limit we may assume 5,000°; the upper limit is more uncertain, but can scarcely exceed 10,000°.

From the preceding considerations we have attained information concerning the temperature conditions of the Sun which will afford us the means of deriving other conclusions, giving an interesting insight into the arrangements of our solar system. We have found, according to our conceptions, that the temperature of the solar surface is very high, although not nearly so high as was supposed a few decades ago. We have incidentally determined a very important number, namely, the amount of energy conveyed by the Sun through its radiation in one minute to an area of one square centimeter at a distance from the Sun equal to the Earth's distance. This latter number (3.75 calories) enables us to determine the total amount of energy radiated, and therefore the amount lost, by the Sun. It is clear that we have only to multiply the solar constant thus found by the total number of square centimeters in the surface of a sphere whose radius is the Earth's distance from the Sun, in order to obtain the amount of energy lost during each minute. A more convenient unit is the total loss for a year, which is given by multiplying the above product by the number of minutes in a year. That it will be an enormous number is at once evident; it is 55×32 with a number of annexed ciphers, which may be more briefly written 55×10^{31}. In most popular astronomies there are attempts to make this enormous amount of heat comprehensible to the layman; such, for example, as the thickness of a layer of ice which it would melt in a year, etc. We shall omit such illustrations, and proceed at once to the further consequences, to do which we must make a simplifying assumption. Since the exact chemical constitution of the Sun is unknown, we must make an assumption as to its specific heat, which quantity is quite different for different substances. For certain reasons, we may conclude that the Sun behaves in this respect similarly to a sphere of water of equal mass. Such a sphere would contain, as may be easily computed, 19×10^{31} grams. The annual diminution in temperature would therefore be $\frac{55 \times 10^{31}}{19 \times 10^{31}}$ or $2^\circ.9$ C.

By this amount, the Sun appears to be cooling each year, and we can therefore estimate the time required for a given reduction, say of one half, in the present temperature of about 7,000°. This estimate is beset with difficulties; for it is quite impossible to state the physical conditions under which the cooling takes place. So much is certain, however, that the lower the temperature becomes the less is the amount of the radiation; and we shall proceed most easily by making the simplest assumption, namely, that the cooling proceeds according to a geometrical progression. Sixteen hundred years is, then, the time required for a reduction of one half in the present temperature. Or, if we compute backwards, we find that at the beginning of our time-reckoning the temperature of the Sun must have been at least double its present value, or about 14,000°.

Now arises the question as to whether or not the effect of such a temperature would be sufficient for us to establish its existence or non-existence from historical information concerning climatic conditions, or flora and fauna. Thus we are compelled to extend our purely physical and astronomical investigations and enter the domain of meteorology, or, more exactly, of climatology.

First, we may determine from STEFAN'S law of radiation the diminution in the solar radiation when the temperature is reduced one half. It is $\sqrt[4]{\frac{1}{2}}$, or seven per cent., a quantity not so small but that we are justified in investigating whether such a change during sixteen hundred years would be susceptible of detection.

That the climatic conditions of the Earth depend upon the solar radiation is evident; but other factors enter, and above all, the heat of the Earth itself, which must not be neglected. Deep borings into the Earth show a moderately rapid increase in temperature, such that in case the same rate of increase continues, a glowing temperature must exist a few miles below the surface. From here heat will be conducted to the surface and radiated into space. Observation shows that the inner heat of the Earth is not sufficient to prevent at the poles a complete covering of the surface with ice; the surface temperature depending upon inner heat alone must therefore be far below the freezing-point. It is only recently that a numerical result has been obtained, ZENKER having found by different methods, which give concordant results, however, the value — 73° for the surface temperature due to internal heat alone. Since the mean surface temperature is actually + 15°, the effect produced by the Sun is an increase amounting to 88°.

The change in radiation during sixteen hundred years brought about by the change in solar temperature we have found to be seven per cent. of its total amount, and therefore at the beginning of our time-reckoning the mean surface temperature must have been 21°; or, to go back sixteen hundred years further, which leaves us still within historical times, it must have been 27°. But of this nothing definite can be said. It follows from geological discoveries that many thousand years ago, perhaps at a time when the Sun belonged to the first spectral type, as suggested by E. DUBOIS, the mean temperature of the Earth's surface must have been much higher than at present, partly on account of the internal temperature of the earth, and partly on account of the doubtless higher solar temperature. But if we go back only five to six thousand years we arrive at the result that for Europe the mean temperature, which at present is about 10°, must have been much lower — probably about 0°; for then Europe was passing through its last glacial period. These glacial periods indicate that during the last thousands of years there has been no considerable reduction in the mean temperature, but only violent periodic variations confined to local areas.

The cause of these variations cannot be sought for in variations in the solar radiation, nor, as has been attempted, in changes in the orbit of the earth; terrestrial changes alone can have influence here — such, for example, as might be brought about for Europe by a change in the course of the Gulf Stream, through volcanic upheavals — perhaps by the breaking through of the Mexican Gulf to the Pacific Ocean beyond.

All considerations of this kind indicate that a reduction in the solar temperature, which must show in the radiation amount, has not taken place during the past few thousand years, and it is therefore clear that there must be active forces which nearly, if not entirely equalize the temperature decrease due to radiation. This equalization may be thought of in two ways: Either there must, by some means, be conducted to the Sun energy from without, so that neither a decrease in temperature nor a diminution in the amount of heat can arise, or there must be, in consequence of internal processes, a maintenance of temperature, not of energy, however. In the latter case, the time during which the equalization can continue is limited, since the internal energy must at last become exhausted; but in the first case the present temperature may be maintained indefinitely, since the inflow of external energy may, on account of the infinity of the universe, be inexhaustible.

We must now examine the means by which energy might be conveyed to the Sun from without. First, we may think of the radiation received by the Sun from the fixed stars, which must send out streams of energy similarly to the Sun itself. The radiation of the fixed stars, even of the brightest, is so slight that its existence has so far been scarcely detected, even with the most sensitive apparatus, although one may think that the total amount received by an enormous sphere like the Sun would not be inconsiderable. A simple reflection, however, shows the impossibility of such an explanation. Upon the above hypothesis, our Earth must be as intensively heated by the stellar radiation as the Sun, and its temperature must be approximately equal to that of the Sun.

A second conceivable means of conveying energy to the Sun, which at the same time would increase its mass, is the bombardment of its surface by meteoric bodies. On account of the ordinarily great velocity of these bodies their kinetic energy and the equivalent heat energy is very great, in spite of their small mass. Formerly great importance was attributed to this means of transference of energy, and its effect was computed, assuming for the number of bombarding meteors a quantity corresponding to the number obtaining for the Earth. This procedure is unjustifiable, however, since it involves the assumption that space is filled to the same extent throughout with meteoric material, which is without doubt incorrect. Of the minute particles scattered throughout the universe which come within the sphere of the Sun's attraction, evidently only an infinitesimal part actually fall upon the Sun; an immeasurably greater number are drawn into closed orbits, so that during the immense periods of time which have elapsed the Sun has gradually become surrounded by a shell of meteoric particles, which, beyond question, are here much more densely packed than in the space without. The shooting-stars and meteors of the Earth depend upon the density of this shell; those of the Sun, only upon the meteoric density of space in general. In this consideration we have omitted the possibility that a great part of the meteors came not from space without, but that they belonged originally to the solar system.

It will be best to compute from the energy loss of the Sun the mass of meteoric particles necessary for the reparation of this loss. A body coming within the reach of the Sun's attraction, and falling upon its surface, attains at the instant of striking a velocity of 607 kilometers per second. In order now to cover an annual loss of 55×10^{31} calories, with this maximum velocity there would be required a mass of 12×10^{18} kilograms, which, if we assign to meteoric masses the specific gravity of iron, of which they are largely constituted, would occupy a space of 1.6×10^{15} cubic meters — a volume equal to that of a sphere of 48 kilometers radius. It is a matter of choice, rather than of scientific discussion, as to whether or not one accepts the probability of the addition of such an enormous mass to the Sun. Such a supposition is not in conflict with the results of observation, for the annual increase in mass is only $\frac{1}{100,000,000,000}$ of the solar mass, a quantity which can have no effect on the planetary motions discoverable by our present observational methods.

On account of the greater meteoric density in the neighborhood of the Earth, a relatively far greater number must fall upon its surface, and we can therefore accept unhesitatingly YOUNG'S conclusion, which states: If meteoric masses were really present in such great numbers, they would fall upon the Earth much more frequently than they actually do. Indeed, the Earth would be struck by such numbers that its temperature would be raised far above the boiling-point of water.

In the beginning of 1880 appeared a theory by WILLIAM

SIEMENS, which at that time aroused great interest, and according to which the energy of the Sun is not dissipated into space, but conducted back to the Sun again.

The idea underlying this theory arises more from philosophical exigencies than from scientific considerations — from the repugnance to the human mind of the knowledge that the solar energy is uselessly squandered; only $\frac{1}{225,000,000}$ of the same finally reaching the planets. Seldom it is, however, that a scientific attempt arising from the influence of the human spirit, or from fancy, becomes of real value. SIEMENS's theory is to-day placed *ad acta*, but deserves, however, upon historical grounds, and on account of its ingenious line of reasoning which is not to be denied, a brief presentation.

SIEMENS assumed space to be filled with extraordinarily rare gases, such as hydrogen, oxygen, nitrogen, and carbon compounds and solid particles of cosmic dust. Each planet attracts these gases and forms about itself an atmosphere, the lower layers of which contain for the most part the heavier gases. The entire solar system is surrounded by a similar atmosphere, whose bulk occupies the space between the planetary atmospheres and extends out into the universe beyond. The rarification is always assumed to be so great that no appreciable influence of friction appears in the motions of the planets.

The rotation of the Sun acts through friction in this envelope like a fan; the gases at the poles are sucked down and move toward the equator, where they are thrown out into space again. Upon approach to the Sun the very rare gases become gradually condensed and thereby heated; upon contact with the atmosphere combustion takes place, and a large amount of heat is generated, which serves to replenish the solar energy. The products of combustion are thrown outward again at the equator. The most important point in the SIEMENS theory is that these products become again regenerated through the energy of the solar radiation. The radiant energy is thereby used, and it cannot continue to pass on into space. The justification of such an assumption SIEMENS derives from experiments by TYNDALL, according to which radiating heat is very powerfully absorbed by water-vapor and other combinations upon the dissociation of the constituent gases. The regenerated gases are drawn back to the poles by the fan-like action of the Sun, are then again burned, and so on throughout an endless repetition.

The SIEMENS theory has become involved in an extensive controversy, and a large number of objections have been raised against it, which, moreover, as must be added, have been partially refuted by SIEMENS. We will here bring forward a single argument against the theory. If the energy loss of the Sun is for the most part to be made good, then there must be constantly directed upon the Sun a stream of energy corresponding in a sense to that which is continually radiated outward. Of the latter we have ample evidence — it is the cause of our existence; but of the former there is no trace. This is the inexplicable contradiction between the SIEMENS theory and the facts of experience.

We are thus led to the unavoidable conclusion that the solar energy is really radiated outward into infinite space, and that it receives no important compensation from without. On the other hand, we have shown with great certainty that up to the present time no considerable reduction in the solar temperature has occurred. We must therefore examine the second hypothesis: Loss of energy, but temporary maintenance of temperature through internal processes.

It is, here as elsewhere, our great physicist, v. HELMHOLTZ, who has proposed a very simple theory and supported it with figures. These latter we shall omit, conformably to the plan of this article, and consider only HELMHOLTZ'S line of reasoning.

v. HELMHOLTZ starts from the KANT-LAPLACE theory of the formation of the solar system, and explains first how the present high temperature of the Sun has come about. Originally, the Sun must have been a widely extended thin nebula of low temperature, which has arrived at its present form through condensation. Such a condensation is nothing more than a falling of the particles of the nebula toward the center, which will, of course, generate heat, just as we have seen is the case in the discussion of the meteoric hypothesis of the conservation of the solar energy. The amount of heat evolved in this way is independent of the time during which the condensation takes place. Were it to take place instantly, the temperature produced would be about 28,611,000°. Since, however, it has been accomplished during an enormously long period of time, so high a temperature as this has never been reached, on account of the constant loss of energy by radiation. Now, since the upper parts of the Sun are gaseous, v. HELMHOLTZ assumed condensation to be still in progress, and in a degree such that the heat thus evolved very nearly compensates for the reduction in temperature.

It is further possible to compute that a contraction of the solar diameter by the ten thousandth part — *i. e.* about 0″.2 — will set free an amount of heat sufficient to raise the temperature of the Sun 2,861°, a quantity sufficient to supply the annual loss of 2°.9 for thirteen hundred years.

The fall of solar material affords therefore a vast amount of heat, which, however, is associated with a constant diminution of the solar diameter; and now arises the question as to whether or not astronomers are in a position to establish this reduction in diameter demanded by the HELMHOLTZ theory.

The determination of the diameter of the Sun is attended with great difficulties, and it is safe to say that such a reduction could be detected only when amounting to at least 1″. With constant solar temperature, this amount would be reached only after six thousand five hundred years; or, in other words, the diminution in the diameter of the Sun resulting from the HELMHOLTZ theory would with our present accuracy of measurement remain undiscoverable for many thousand years. The results of observation therefore afford no ground for doubting the conservation of the solar temperature, the theoretical possibility of which is raised above all doubt. Naturally, there must at last come a time when the possibility of further condensation is at an end, and then an actual diminution in temperature will begin.

We approach the end of our discussion. We have learned the vast amount of the stream of energy pouring out from the Sun, and we have been able to assert that all the vivifying forces of our Earth will remain unchanged for an immeasurable series of thousands of years. This period of time, so enormous for our conception, is but an instant according to the timepiece of the universe. Inevitably the time will come when, according to the classical utterance of DUBOIS REYMOND, the last Eskimo will wretchedly freeze at the equator by the light of a tallow-dip, and the last moment will not fail when all life upon the ice-bound earth will have ceased, and with it the last knowledge of all the thousands of years of strifes and battles of the human race, and of all of its acquisitions of civilization. Death is the end not for the individual alone; it is also, of all things upon this world, the end.